Testing the efficacy of voluntary urban greenhouse gas emissions inventories

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Abstract:

Drawing from an original dataset of urban metropolitan carbon footprints, in this paper we explore the correlations between national level climate change commitments and sub-national level inventories. We ask: Does ambitiousness in commitment have an impact on performance in footprint reduction? Does having long-term commitments affect performance in footprint reduction? Do binding national level commitments (such as those under the Kyoto Protocol) affect performance at the city level in terms of footprint reduction? To provide answers, we synthesize data from the largest repository of voluntary sub-national commitments and actions towards footprint reduction and greenhouse gas inventories from around the world, the Carbon*n* platform. More than 500 cities report at least one action, commitment or inventory to this database. We find, using a subset of this database, perhaps counter intuitively that cities with more ambitious commitments do not necessarily have steeper reductions in emissions. Our data also suggests that having long-term self-reported goals did not make the cities perform better in terms of footprint reduction. This appeared to be true for both government and community commitments reported. Lastly, and positively, our data did reveal a statistically significant effect for cities belonging to countries that had committed to the Kyoto Protocol, suggesting the necessity of binding national (and supranational) climate targets.

Keywords: metropolitan carbon footprints; greenhouse gas emissions inventories; Kyoto Protocol

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1. Introduction

With the increasing focus on binding national commitments in the wake of the Paris agreement, the role of non-binding commitments at the sub-national level to mitigate greenhouse gas emissions needs closely examined. During the intervening period between the annulment of Kyoto protocol and the adoption of subsequent binding national commitments, cities stepped up as the leading sub-national entities driving a climate change mitigation agenda (Lee and Koski 2015). Voluntary engagements at the urban level such as covenant of mayors emerged. Indeed, the reasons for comparatively more active engagement at the city level have not been studied in systematic detail despite the fact that specific initiatives appear to make climate action at the city level more practical as compared to commitment and delivery at other scales. Increasing urbanization, changing consumption patterns and increasing overall urban emissions as a share of total at the urban level have also been phenomenon that need to be taken into account.

One of the key examples of the ability and willingness of cities to take action on climate has been the comparatively greater willingness of city government and such urban institutions to define and commit to voluntary footprint reduction targets. Even in countries like the US where political expediency has made it difficult for national government to pursue ambitious climate goals, cities have shown impressive initiatives towards the goals of footprint reduction (Strauss et al. 2015). However coordination between national and sub-national governments towards aligning those targets as well as literature exploring the effectiveness of such coordination continues to be limited. A number of relevant frameworks have been proposed for integrating multi-level governance across cities and nation states and most argue for greater autonomy for cities (Corfee-Morlot and et al.). In most cases sub-national entities are found to be acting independently of the long term planning at each level. Better coordination across governance hierarchies is definitely expected to facilitate greater ambition and achievement on climate change at the national level (Hanssen et al. 2013).

In this paper we explore the correlations between national level commitments and sub-national level inventories and emissions reductions by looking at data from the Carbon*n* platform, which has been used by cities to report actions, commitments and inventories since 2010 (ICLEI et al. 2015). More than 500 cities from around the world report at least one action, or commitment or inventory on the database. We use the dataset to explore three questions:

1. Do cities with voluntary commitments perform better than those without?
2. Do short-term or longer-term commitments, or more aggressive commitments, correlate with the fastest reductions in emissions?
3. Did the degree of emissions of reduction—performance—improve after the Kyoto Protocol entered into force?

In proceeding to answer these questions, the study makes at least two contributions. Mobilizing cities and other scales of action below the nation-state has become a defining feature of governance, public policy, and political science, and it is one that extends well beyond state-led efforts at international regime building (Gupta 2010; Ostrom 2010). First, our study tests the efficacy of voluntary governance and subnational actors in addressing one incredibly important environmental problem, climate change. Second, an abundance of peer-reviewed literature over the past two decades has treated the Kyoto

Protocol as a failure (Nordhaus 2015; Reilly et al. 1999; Victor 2004; Victor 2006). Our results, interestingly, suggest that such harsh criticism of the Accord may be unwarranted.

It should be noted that while we make some headway towards answering the above questions using the Carbon*n* dataset, the limitations of the data (which shall be explained in detail in a subsection) and the nature of the inventories reported also have salient research findings for climate policy analysts and practitioners, which we explore in the later parts of the manuscript.

What follows is a description of our dataset, our methodology, and our findings. In summary we will describing the Carbon*n* dataset, the indicator for urban performance developed, the list of cities that have adequate data for each of the comparisons to be performed in this paper. The results and limitations of the findings are discussed in greater detail as well.

2. Materials and Methods

This section of the paper beings by introducing readers to the Carbon*n* database and our research design.

2.1. The Carbon*n* Database of Urban Carbon Commitments

Our primary dataset for this article is the Carbon*n* database, one that we maintain is the largest global self-reported repository of voluntary urban footprint reduction commitments. Though the database reports commitments and reductions in tons of CO_2 equivalents, the footprint reduction activities can include anything from commitments towards increasing local food security to reducing per capita water usage. Cities use various methods to estimate the carbon footprint reduction potential of specific actions. The extensive geographical coverage, bottom-up inventories, broad thematic scope and self-reporting make Carbon*n* database the only and largest database of its kind.

To be sure, there are other datasets in the literature (Butler and Lawrence 2009; Butler et al. 2008; Dhakal 2010; Duren and Miller 2012; Hoornweg et al. 2011; Hsu et al. 2016; Kennedy et al. 2014; Kennedy et al. 2011; Marcotullio et al. 2014; Sovacool and Brown 2010), albeit with smaller number of cities. Some of them do not provide comparability across the board (Al-areqi et al. 2014), are limited to one country (US Census Bureau 2007; US Census Bureau 2010) or do not provide bottom-up estimates (Dodman 2009; Lee and Koski 2015; Marcotullio et al. 2014). Other datasets or reports provide high level assessments without engaging in detailed quantitative analysis (Grubler and Fisk 2013; United Nations 2010). What makes ICLEI's database unique is that it provides the largest number of cities with multiple inventories allowing for estimation of trends. Some secondary databases extract some of the information from ICLEI database for generalized assessment at a cumulative level. The problem of standardization for comparability across the board (Bleischwitz and Nikolas 2009) is also being addressed by the development of the GHG protocol for cities (GPC) and reporting on it (ICLEI et al. 2013). Carbonn also continues to be the largest database of cities reporting on GPC however multiple inventories meeting GPC are not available in the ICLEI database. This makes the dataset analyzed in this paper the largest dataset with multiple urban inventories allowing for comparison in trends.

The Carbon*n* dataset consists primarily of three different sets of data. The first type of data contains all the self-reported commitments from the cities. The second type of data consists of self-reported inventories or yearly carbon emission stocks in tons of CO_2 equivalent. The third type of data consists of list and details of actions that the cities have taken to achieve the self-reported commitments.

As of March 2016, the commitments table consists of 1115 commitments from 385 cities. These commitments are broadly divided in ‘community’ commitments and ‘government’ commitments. The community commitments are commitment for the entire community or the entire city while the government commitments are commitments only for government controlled facilities, transport and industries. For each of the community and government categories the reported commitments are further classified into energy efficiency, renewable energy or greenhouse gas reductions. The commitments are reported as percentage reduction from the base value and for each commitment a base value year and a target year have been specified.

The performance inventories are also divided into community and government inventories. A total of 216 community inventories from 108 cities while a total of 186 government inventories from 114 cities are available in the database. This means that some cities report multiple years of inventories. This is the aspect of the data that allows us to estimate trends and do quantitative correlation studies with the calculated trends. The inventories are reported in sub-categories for different sectors from industrial, domestic, transport to waste and others.

To be fair, not all cities report all inventories for all sectors which means that comparative analysis with cumulative inventories across the cities needs to be cognizant of the variations in sectoral reporting from the cities. However as we describe in the analysis section, since this study only compares ‘trends’ or one specific measure of trend calculated here across the entire set of cities, and since this trend is calculated by only comparing a city’s performance against its own past performance, the fact that cities may measure inventories across different sectors is of no consequence. In calculating a trend, each city is being measured only against its self. That some cities choose to monitor some sectors more stringently compared to others only thus becomes a factor within their overall strategy that is being analyzed through a comparative study of ‘trends’ as measured here in urban footprint due to reduction policies, strategies and actions. In total there are 166 cities with at least one commitment and one action. These are the cities included in the Earth Hour City Challenge (EHCC) for the year 2014 (WWF 2015). EHCC is a program that encourages cities to report inventories, commitments and actions on the ICLEI database. The most ambitious cities are selected as Earth Hour Capitals of their respective country and one city is selected as the Earth Hour Capital of the world.

Lastly, the database consists of a detailed set of specific actions that the cities have reported in pursuit of their commitments. These number in the thousands and reporting on these actions is not standardized with several cities merely attaching relevant planning documents to the database. This dataset is currently being analyzed and the study shall be further expanded to include this dataset in the analysis in the future, potentially to explore relevant successful and unsuccessful case studies in a systematic manner. The results presented in this paper do not take into account the actions dataset.

2.2. Research design and analysis

In order to have a higher level but broad assessment of the effectiveness in footprint reduction we define the term ‘urban footprint reduction performance quotient’ or ‘strain’. This quotient is defined as the change in urban carbon footprint per year, normalized to base footprint. Since it is difficult to have universally comparative measures of urban policy effectiveness we measure effectiveness in footprint reduction only as change from the original values or 'strain'. This is done because while in some cities, change in per capita carbon emissions could be relevant, due to the differing nature of expansion of cities overtime, per capita estimates won't be as relevant. For say a North American city which may not have witnessed extensive population growth compared to say an Asian city, the growth in per capita carbon emission overtime due to sprawl or lateral expansion would skew the analysis. On the other hand if a city starts out with high population density, it already has an advantage over lower density cities which cannot be observed in temporal trend over a matter of a few years. We thus measure trend only as quantification of change in carbon emissions normalized to the original carbon emissions for the city or the carbon emissions at the point of the first temporal measurement in the time series.

Admittedly, there are multiple reasons why we employ the analogic term 'strain' to denote this quotient. Firstly we need to have terminology that captures the non-linearity in response exhibited by most urban systems when confronted with policy action or other stimuli. The term strain implies that just as in physical systems there may not be any change in urban system in response to initial efforts. Following a tipping point however we may see the system undergo rapid transformation. Further the term 'strain' also readily communicates the fact that this is a unit-less measure indicative only of internal ability of the system to modify itself. As such the comparisons presented are not measures of how much a city has changed relative to others but how much it has changed in relation to its own initial conditions. Also, as a practical necessity the term 'strain' captures the uniqueness of the measure developed here in a mass of urban footprint reduction measures already found in literature. Going forward we will use the term terms performance, strain and trend interchangeably in this paper.

We thus define urban strain ε for any given city with n inventories simply as;

$$\varepsilon = \frac{\Delta I}{I_0}$$

Where;

$$\Delta I = (I_n - I_0) \,/\, (T_n - T_0) \text{ for cities with } n = 2 \text{, where;}$$

$$I_n = \text{inventory for nth year } T_n$$

$$I_0 = \text{inventory for base year } T_0$$

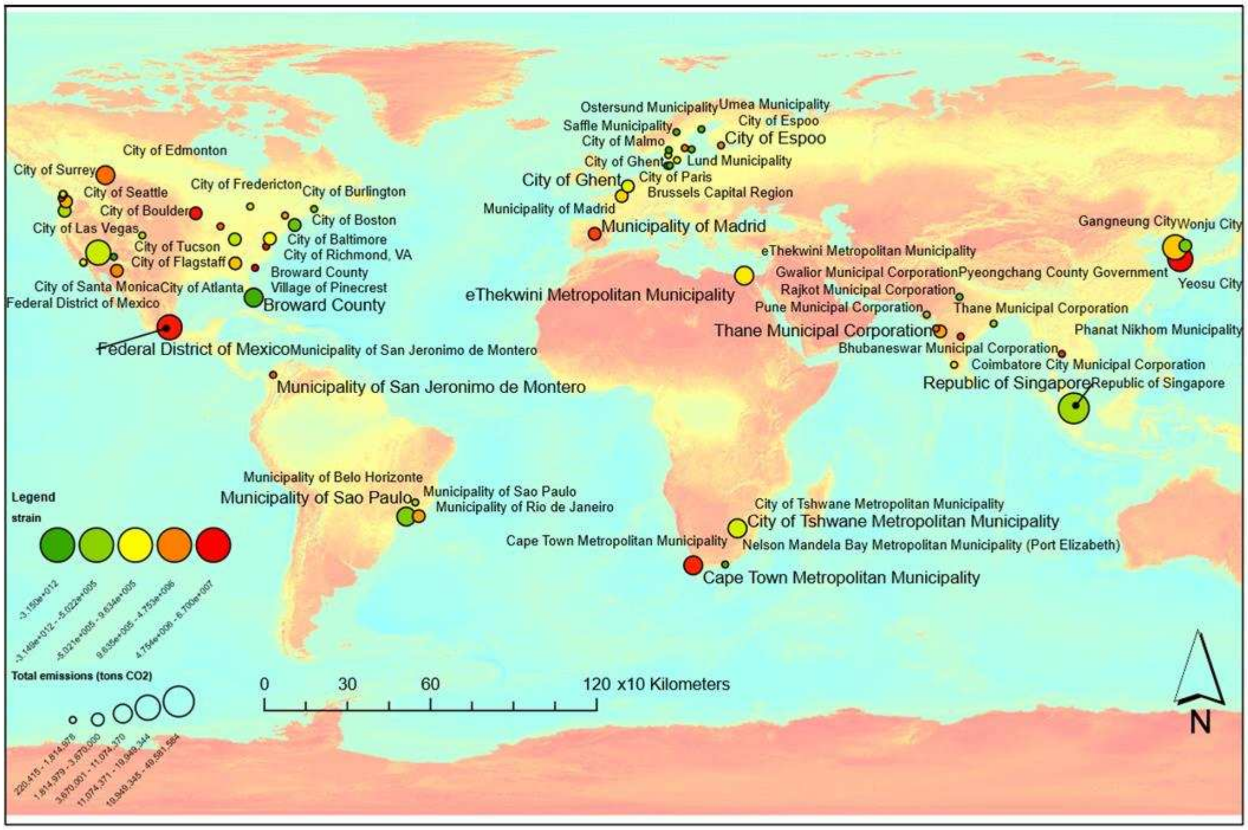
While;

$$\Delta I = \textit{slope of best fit regression line} \text{ for inventories } I_0 \text{ to } I_n \text{ against time period } T_0 \text{ to } T_n \text{ for } n > 2$$

Thus, urban footprint reduction strain is a straightforward way of measuring changes in carbon emission inventories. A negative strain would represent a reduction in carbon footprint over the years while a positive strain would represent an increase in carbon footprint with the magnitude of the strain indicative of change with respect to the base value. As can also be observed from above discussion, in order to estimate this strain a city needed to have at least two inventories, meaning all other urban areas with incomplete data were excluded from this particular analysis. Further, in order to have a comparison of how the reporting cities fared against national averages, the strains were also calculated for all the countries included in the city analysis using national carbon inventories (World Bank 2011).

In order to analyze the impact of ambitiousness in target setting upon the trend or footprint strain the correlation of the community commitments to the community trends was studied. To be included in this analysis the cities needed to have at least two community inventories and at least one community commitment. This reduced the selection of cities from 166 to 25 cities. These 25 cities are shown in **Figure 1** along with all other cities that have reported more than one community performance.

Figure 1. Cities with more than one community commitments with color representing strain (ε) and size representing total carbon emissions in tons of CO_2 equivalent



The 25 cities came from nine countries and five continents and included cities from the global north and global south (India and Brazil). Although 25 cities do not represent an extensively large dataset of cities, it does capture some measure of representation from broad categories of living arrangements and city type. The list of cities along with the trends and commitments are shown in **Table 1**.

Table 1. Cities with community urban footprint strain and commitments (shaded cities also report long-term commitments)

Country	Name of local government	Base inventory year	Total inventory (tons of CO_2 equivalent)	Trend ΔI (tons of CO_2 equivalent)	Trend normalized to base (ε)
Brazil	Municipality of Belo Horizonte	2007	2992595	86988	0.029068
Brazil	Municipality of Rio de Janeiro	2005	--*	4998295	0.534274
Canada	City of Vancouver	2008	2842740	-50087.1	-0.01762
Canada	City of North Vancouver	2005	220415	-2316.2	-0.01051
Canada	Corporation of Delta	2007	861535	-5106.33	-0.00593
Finland	City of Espoo	1990	1384407	21943.16	0.01585
France	City of Paris	2004	12729300	-114120	-0.00897
India	Thane Municipal Corporation	1990	2327233	15499.36	0.00666
India	Coimbatore Municipal Corporation	2008	1394642	24970	0.017904
India	Rajkot Municipal Corporation	2007	--*	955976.8	1.083747
Republic of Korea	Seoul Metropolitan Government	2010	49581584	-1590486	-0.03208
South Africa	City of Tshwane Metropolitan Municipality	2007	16292831	-718017	-0.04407
South Africa	Cape Town Metropolitan Municipality	2007	19949344	-118269	-0.00593
Sweden	Vaxja Municipality	1993	326763	-5244.43	-0.01605
Sweden	City of Stockholm	1990	3670000	-42553.5	-0.01159
Sweden	Vasteras Municipality	1990	918500	-5760.51	-0.00627
Sweden	City of Malmo	1990	1425000	19766.14	0.013871
United States	City of Burlington	2007	432422	-62766.7	-0.14515
United States	City of Cincinnati	2006	8470477	-774752	-0.09146
United States	City of Seattle	2008	7041574	-227394	-0.03229
United States	City of Evanston	2005	1003807	-16143.9	-0.01608
United States	City of Boston	2005	7535298	-88631.6	-0.01176
United States	City of Manhattan Beach	2005	--*	-3339	-0.00986
United States	City of Boulder	2006	1814978	-10430.5	-0.00575
United States	City of Santa Monica	1990	822511	-719.74	-0.00088

*local governments have requested upon reporting to the Carbon*n* Climate Registry that their total GHG emissions remain confidential

Our second research question was to explore the difference in performance between cities that reported and cities that did not report commitments at all. For community commitments and trends we had the same set of 25 cities. However there were 13 cities that had at least two community inventories but reported no commitments. The list of these cities is shown in **Table 2**. This set of cities also included representation from all five continents and both developed and developing nations. Shapiro-Wilk testing for normality revealed that the trends or strains were not normally distributed.

Table 2. Cities with at least two community inventories but no commitments

Country	Name of local government	Base inventory year	Total inventory (tons of CO_2 equivalent)	Trend ΔI (tons of CO_2 equivalent)	Trend normalized to base (ε)
Brazil	Municipality of São Paulo	2003	14893563	48122.13	0.003231
Canada	City of Edmonton	2008	19964246	-731911	-0.03666
Columbia	City of San Jerónimo de Montería	2009	--*	-106218	-0.08592
Korea	City of Changwon	2005	7677961	179964	0.023439
Korea	City of Pyeong Chang	2005	492082	20307.2	0.041268
Korea	City of Suwon	2005	6225737	-8780.6	-0.00141
Korea	City of Wonju	2005	--*	108433.5	0.085207
Korea	City of Yeosu	2005	29664037	915286.5	0.030855
Korea	Gangneung City	2005	7124024	484499	0.068009
Sweden	City of Umeå	1990	370296	-7234.78	-0.01954
USA	City of Las Vegas	2011	27803600	66999502	2.409742
USA	City of Minneapolis	2006	5816425	-150443	-0.02587
USA	City of Portland, OR	1990	8549827	2392898	0.279877

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To study if the trends in cities with commitments and the trends in cities without commitment reporting came from the same underlying distribution, non-parametric testing was needed. Kolmogorov-Smirnoff and Mann-Whitney-Wilcoxon tests were then used to evaluate if the trends in cities with or without commitments were the same. The trend calculations are shown in **Table 3** while the results of the statistical testing are shown in **Table 5** and discussed in detail in the results section. Similar analysis was conducted for cities with at least one government commitment and two government inventories. 18 cities had at least one commitment and two inventories (**Table 3**) while only 12 cities had inventories but no government commitments (**Table 4**). These cities enable us to explore if having long-term commitments had an impact on the performance of cities in terms of the trend or strain measured here. For this we needed to compare cities with long-term commitments and cities without long-term commitments. For community commitments, all of the cities needed to have at least one community commitment and two inventories. Of these 25 cities identified earlier, there were 11 cities that had long-term commitments and 14 cities that had no long-term commitments. Long-term here is defined as post-2020 commitment.

Table 3. Cities with government urban carbon footprints and commitments (shaded cities also report long-term commitments)

Country	Name of Local Government	Base inventory year	Total inventory (tons of CO_2 equivalent)	Trend ΔI (tons of CO_2 equivalent)	Trend normalized to base (ε)
Canada	City of Edmonton	2008	381465	10746.28571	0.028171092

Canada	City of North Vancouver, British Columbia	2005	2712	-42.68333333	-0.015738692
Canada	City of Vancouver	2008	495950	-21395.35714	-0.043140149
Canada	The Corporation of Delta	2007	7864	-74.8447205	-0.009517386
France	City of Paris	2004	205900	1760	0.008547839
India	Coimbatore Municipal Corporation	2008	13717	-3651	-0.266166071
South Africa	Cape Town Metropolitan Municipality	2007	334306	24279.4	0.072626277
South Africa	Tshwane Municipality (Pretoria)	2007	1333551	543335.8333	0.407435361
Sweden	City of Västerås	2009	77545	-1587.371429	-0.020470326
Sweden	City of Växjö	2005	15225	-510.4451613	-0.033526776
USA	City of Beaverton	2008	10726	-796.4571429	-0.074254815
USA	City of Boulder	2008	67104	-7114.333333	-0.106019512
USA	City of Cincinnati	2006	432179	-29034	-0.067180497
USA	City of Cleveland	2010	358148	-3405	-0.009507243
USA	City of Columbus	2005	317927	411872.875	1.295495114
USA	City of Evanston	2005	24559	-1084.6	-0.044163036
USA	City of Las Vegas	2011	116650	-30154	-0.258499786
USA	City of Santa Monica	1990	24108	711.2992126	0.029504696

Table 4. Cities with at least two government inventories (strain calculable) but no commitments

Country	Name of local government	Base inventory year	Total inventory (tons of CO_2 equivalent)	Trend ΔI (tons of CO_2 equivalent)	Trend normalized to base (ε)

Canada	City of Yellowknife	2004	5140	-264.8	-0.05151751
Columbia	City of San Jerónimo de Montería	2009	--*	7625.333333	2.568317054
Finland	City of Espoo	1990	26208	-483.7980132	-0.018459936
India	Rajkot Municipal Corporation	2007	--*	954.3648649	0.022354653
India	Thane Municipal Corporation	1990	42379	250.4736842	0.005910325
Korea	Seoul Metropolitan Government	2010	3355546	105763	0.031518865
Sweden	City of Stockholm	2006	320000	-25300	-0.0790625
Thailand	Municipality of Sisaket	2011	58854	-24219	-0.411509838
Thailand	Yasothon Municipality	2012	37044	-361	-0.009745168
USA	City of Hillsboro	2007	21545	-1903.5	-0.088349965
USA	City of Houston	2005	1112539	22990.4	0.020664804
USA	City of Manhattan Beach	2005	--*	-173.5	-0.037104363

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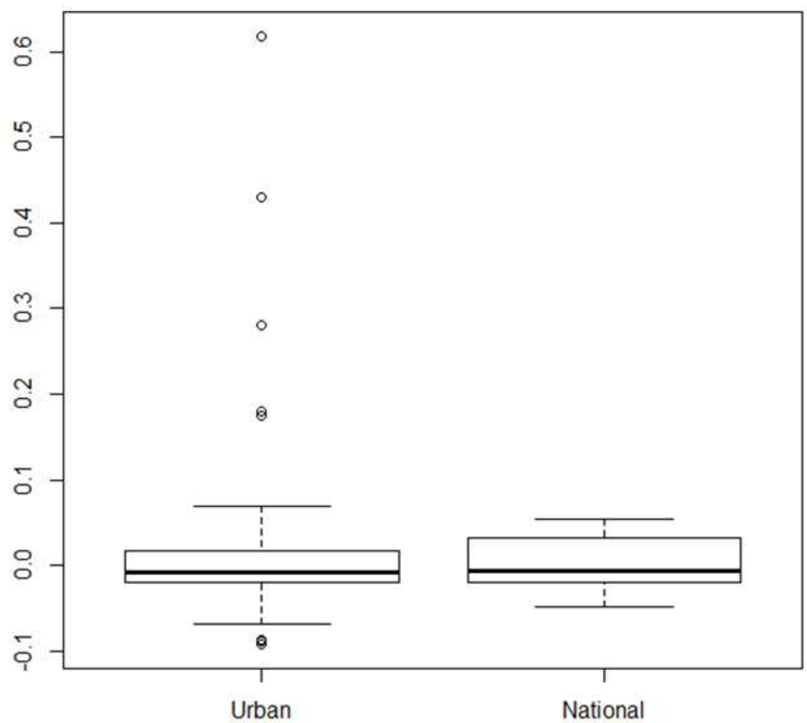
Lastly, we aimed to analyze the impact of national level binding agreements on city performance. The only instance to assess this factor involved implementation of and compliance with the Kyoto protocol. As the Kyoto Protocol entered into force in 2007 and its commitment period started in 2008 and went on till 2012, the cut-off date was taken to be 2007. Trends up to 2007 was compared to trend after 2007. To perform this analysis thus we needed cities with at least three inventories, firstly inventories up to 2007 and then inventories after 2007. Only 10 cities had enough community inventories and only 6 had enough government inventories to perform this analysis. Only Canada, USA, Sweden and India had cities that met the criteria. As such we still had representation of cities from three continents and both developed and developing nations. The list of cities with data is presented in supplementary **Table S1**. Non-parametric testing was also used to compare pre and post Kyoto performance for cities with community inventories while a student's T-test was used to compare pre and post Kyoto performance for cities with government inventories.

3. Results and Discussion

Firstly we performed a quick comparative analysis of how cities that were reporting multiple inventories compared to the national averages. It has been observed in smaller scale studies that reporting cities do not appear on average to do better than the country in terms of footprint reduction (Kennedy et al. 2012). Surprisingly this was found to be the case in our study as well. The average performance indicator for both national and urban footprint reduction was virtually similar at -0.0068. As can be seen in **Figure 2** however, a lot more variation was observed in urban performance as opposed to national performance (even after excluding outlying cities). This result is also expected as the varying profiles of cities naturally lead to larger variation as compared to national level change in carbon footprint, which is influenced more uniformly by global economic and policy process. Still the remarkable similarity in average footprint reduction between cities and nation states indicate that generally speaking cities still need more freedom to pursue effective policy in the sphere of footprint reduction than is currently afforded. National and global policy and process still hold sway.

Figure 2: Boxplot for urban and national performance indicator show cities reporting have the same median footprint reduction performance as countries but with greater variation



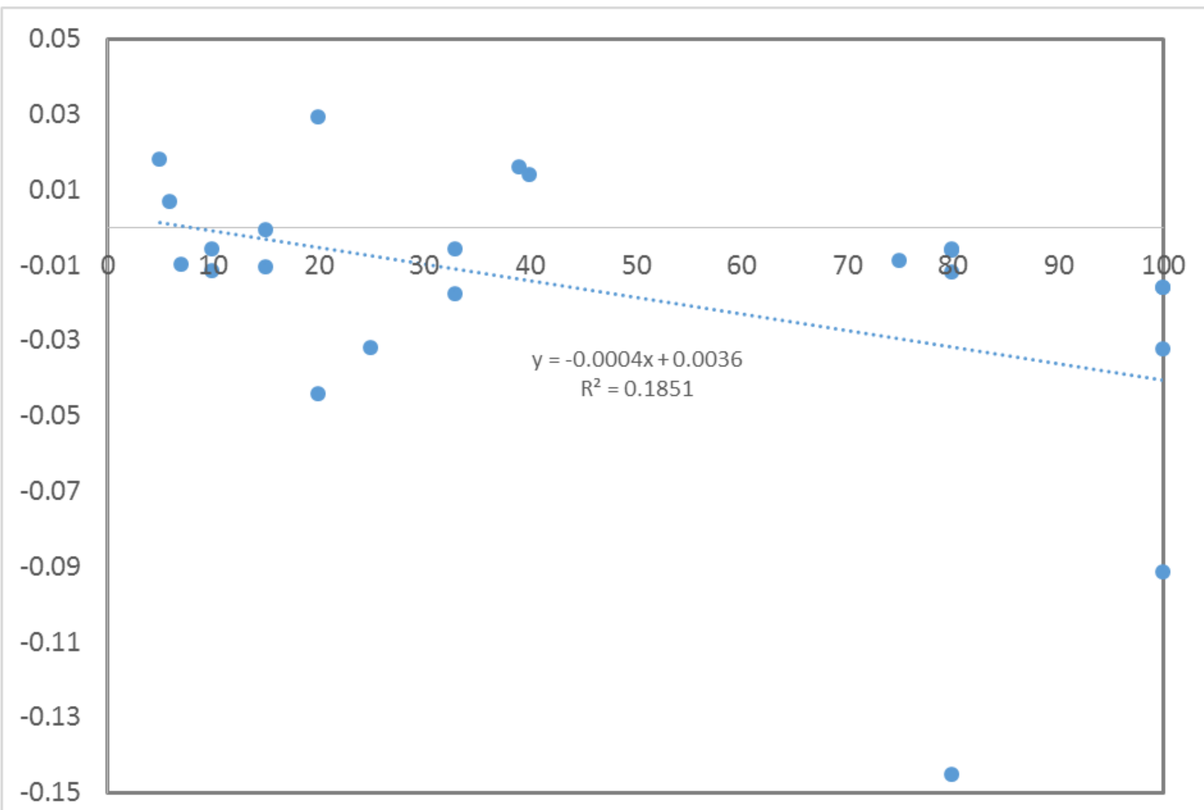
As context to the analysis that follows it should be emphasized again that multiple external factors contribute to footprint reduction or increase in the city and these may not have any correlations with urban level policy or development (Kennedy et al. 2014; Mohareb and Kennedy 2014). This can include for instance, a) global economic conditions; post 2008 financial crises a number of cities around the world may have reduction in energy consumption and carbon emissions growth rates, b) national policy; especially in countries with centralized governance such as China, the direction national government takes heavily influences what happens in cities, c) climatic change and natural disasters; with the increasing frequency and intensity have more and more potential to disrupt the normal 'trends' that we have been trying to study here through high level measurements, and d) other factors external to what happens in the city. In the following analysis we try to take into account such factors while describing the trends we observe. Our finding however should not be taken as evidence for discounting qualitative analysis of external factors or local significance.

Of all the other comparisons, interestingly, only in one dimension—cities with a country committing to the Kyoto Protocol—do we see a statistically significant effect.

3.1. Urban commitments do not necessarily translate into emissions reductions

The first result we observed in the data was that there was no strong correlation between urban community inventory trends or strain and the community commitments. This can be seen in **Figure 3**. Such correlations were explored for a no. of dependent variables ranging from specific commitments from specific sectors both for community and government reported commitments. Though the result only for one such correlation is shown here in **Figure 3**, the magnitude of the reported commitments for either government or community boundaries, and for any sector or accumulation of sectors did not seem to have an impact on the trend.

Figure 3. Regression analysis between urban community commitment and footprint strain



There could be several reasons why we don't observe a stronger correlation between the magnitude of commitments reported and the degree of urban strain. The strains aren't all calculated for all periods that fall within the commitment periods. Voluntary commitments are also politically derived numbers influenced by varying social and political factors including political leadership and changes within it, including the constantly shifting electoral landscape and other bureaucratic concerns. The commitments are as such more symbolic rather than substantive, and could reflect only aspirations rather than realities in actual implementation actions or urban planning. In future work we plan to explore urban commitments at a deeper level by analyzing reporting actions. For the current analysis commitments are taken as proxies for motivation for action at the urban level.

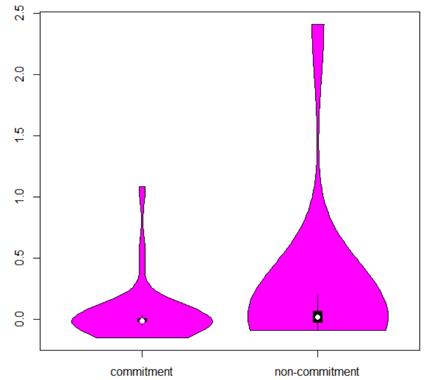
3.2. Larger commitments do not translate into greater emissions reductions

We next looked at the impact of commitments as a binary irrespective of the magnitude of commitments. Cities reporting commitments and cities not reporting commitments were compared for the trend in their performance using non-parametric testing. The results are shown in **Table 5**. **Figure 4** visualizes the two distributions in the form of a violin plot. As could be seen the non-parametric tests reveal that there isn't statistically significant evidence that the underlying distributions for the two groups are dissimilar or that they come from different populations. This appears to be true both for community commitments and for government commitments. Based on analysis of self-reported commitments and strain or trends in urban footprint calculated against base trend, the act of self-reporting commitments does not influence the performance of cities towards reducing footprint.

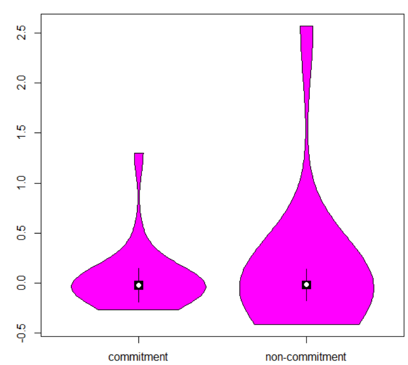
Table 5. Statistical test results for different comparisons

	Kolmogorov-Smirnov test			Mann-Whitney-Wilcoxon Test			T-test		
	D	p-value	result	W	p-value	result	P	T critical	result
Commitment vs. no commitment (community)	0.4185	0.06342	No significant difference	212	0.133	No significant difference	Non-parametric data - test not relevant		
Commitment vs. no commitment (government)	0.111	1	No difference	108	1	No difference	Non-parametric data - test not relevant		
Long-term commiment vs. no long-term commitment (Community)	0.2013	0.9108	No difference	88	0.5719	No difference	Non-parametric data - test not relevant		
Long-term commiment vs. no long-term commitment (Government)	0.2857	0.7768	No difference	35	0.7914	No difference	Non-parametric data - test not relevant		
Pre Kyoto vs. During Kyoto (Community)	0.6	0.05245	Different at 6% probability	70	1431	No difference	Non-parametric data - test not relevant		
Pre Kyoto vs. During Kyoto (Government)	Parametric data - test not relevant			Parametric data - test not relevant			0.97	2.57	Significantly higher post Kyoto reductions

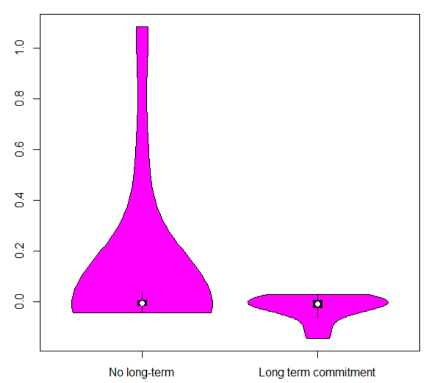
Figure 4. Violin plots comparing the distribution of footprint reduction trends for various city groups



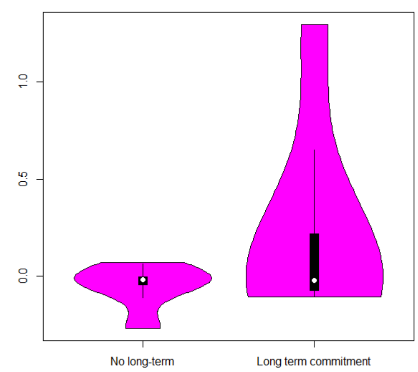
Cities reporting community commitment vs. not



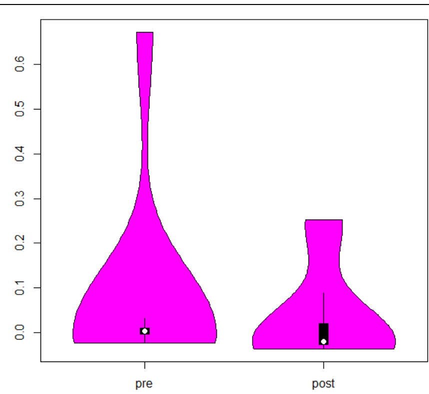
Cities reporting government commitment vs. not



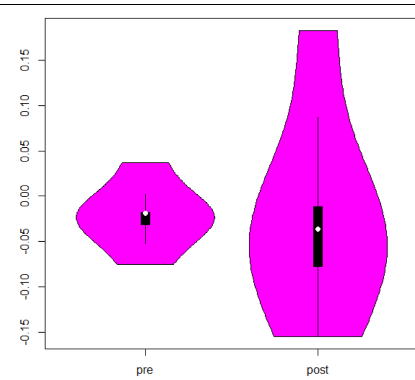
Cities reporting long-term community commitment vs. not



Cities reporting long-term government commitment vs. not



Post Kyoto community performance vs. pre



Post Kyoto government performance vs. pre

Moreover, our data suggests that having long-term self-reported goals did not make the cities perform better in terms of footprint reduction. This appeared to be true for both government and community commitments reported. This is perhaps further indication that the act of self-reporting voluntary commitments, especially for the long term, is not necessarily a process or policy driven act. There might be significant political and social impulses driving the determination of these goals or commitments, and that the decision may not have been internalized by all levels of decision making. In most cases long term commitments do not necessarily have stakeholders buy in at all adequate levels to affect performance. Thus, those with actual direct control over emissions, such as energy suppliers, industrial firms, and even households, may feel excluded and thus remain difficult to influence from urban planners.

3.3. Urban emissions reductions did accelerate after Kyoto in 2007

Comparison of pre and post Kyoto performance yield our only positive result. While there was a very small difference between urban footprint reduction trend measured as strain for urban inventories for the entire community, for government facilities and inventories, the performance of cities was significantly better during the Kyoto commitment period as opposed to before it. The T test comparison results for government inventories show a P critical two tail value of 0.97 for a t critical of 2.57 indicating that there is a high likelihood that there is a significant difference between the trends for pre and post Kyoto reductions. The results for community inventories and violin plots are included in **Table 6** and **Figure 4**. It appears that national level binding commitments do have some impact on urban performance despite the apparent decoupling in policy and legal processes.

While this may appear a result with obvious causality, suggesting that emissions reductions post-Kyoto can be attributed to only Kyoto is not a certainty. Of the four countries studied only two, Canada and Sweden ratified Kyoto and Canada did not meet its commitments. One other contributing factor could have been the global economic downturn beginning in 2008 that had a negative effect on global economic activity but a proportionally positive effect on global carbon footprint might have affected the reduction. Another could be the rise of natural gas, especially in the sample of cities belonging to the United States, and its general influence in lowering the carbon footprint of electricity systems as it displaces coal. However the fact that reduction is seen in one dataset (government) and not the other dataset (community) indicates that exogenous economic and technological factors might not have been as significant.

3.4. Limitations and future research gaps

To be candid, the results presented above should be considered in light of the limitations of the database and the analysis methods employed. We note at least five of them here, and believe they point the way towards fruitful future research efforts.

Firstly, the data is self-reported with varying levels of quality control. ICLEI and WWF offices worldwide train city professionals to input the data however there may be some methodological discrepancies. As such the primary use of the data should be to see it as an expression of the city's intention to reduce emissions rather than an actual accounting mechanism. We maintain this limitation does not negate the value in testing city intentions with performance.

Secondly, cities may be using different methodologies to calculate inventories and might be drawing on different sectors (Ibrahim et al. 2012). Once again, this adds to the lack of standardization across the entire set of cities. While this is a problem being worked on by ICLEI and WWF EHCC programs in coordination with the cities, in the meanwhile the data still serves as a useful expression of urban intensions. Again development of GPC is a positive development in this area and as inventories for multiple years for cities become available overtime, comparison would be much more robust. As such, if urban performance is measured against the earlier performance of cities, and the trends are seen as a percentage change or unit of strain normalized to base values, as we have done, broad comparisons are still possible.

Thirdly, in a small number of cases the trends in inventory presumed to be linear are not. North Vancouver, Canada for instance shows an upward trend in inventory pre-2007 and a downward trend after. This reversal is captured only in the comparison on pre and post Kyoto strains and not in other analyses or comparisons. The magnitude of such reversals though is small and only relevant for less than five percent of the cities. It does not have significant enough effect on the overall trend to influence the conclusions or merit specific calculations.

Fourthly, the final set of cities used for various comparisons and analyses after selecting for conditions such as availability of two or three inventories is small and varies in size from six to twenty five cities. For all analyses we still have representation from North America, Europe, Asia, developing and developed nations and for most analyses the number of cities considered is greater than most similar comparative studies in literature, i.e. having bottom up figures or utilizing small set of cities(Butler and Lawrence 2009; Butler et al. 2008; De Sherbinin and Chen 2005; Dhakal 2010; Duren and Miller 2012; Gately et al. 2015; Kennedy et al. 2011; Marcotullio et al. 2014; Satterthwaite 2008; Sovacool and Brown 2010; Xu et al. 2015). This makes this study one of the largest of its kind with such a varied set of cities from different regions and geopolitical contexts.

Fifthly, the sample sizes for the analysis may still not be large enough in the case of comparison of pre and post Kyoto values for the commentary and results to have statistical significance for all cities worldwide. Still, with the varied representation of cities and regions even in the smallest set of 6 cities (which includes, North America, European, Asian cities as well as cities from developing and developed nations), indicative conclusions may be drawn.

Our findings therefore needed bracketed within the uncertainties of the data used and the limitations described above.

4. Conclusion

Notwithstanding these admitted shortcomings, our results do raise some troubling and perhaps far-reaching implications in the domain of climate policy and planning. In light of the recent Paris agreement it is of significance to note that, despite the more active role of cities compared to national governments towards climate action, national level binding commitments have more of a differentiating impact on performance at city level than many other indications of city level commitment.

This emphasizes that while city level voluntary action will be crucial in the future to mitigate emissions, and while such action continues to be easier to facilitate given the different sociopolitical context in which cities operate, national level binding commitments will be absolutely necessary. Put in very simple terms, countries and national commitments seem to “matter” more than those arising from subnational scales such as cities, urban areas, and metropolitan districts.

The nature of this finding has potentially far reaching implications. Though cities can and should continue to be viewed as necessary in the fight against climate change, and in some cases may even act as useful testbeds or “laboratories of democracy” where they can undertake experiments in climate and energy policy, it is at the larger, national scale that we seem to see more efficacious climate interventions. Perhaps this is because the nation state remains where most energy planning and policymaking takes place. Moreover, despite the rise of new modes of governance above and below the state, most key political decisions are still made at the state level, and the state-based international system has exhibited a high degree of resilience. Nations and the commitments they make under global climate agreements should therefore remain front and center in future climate policy discussions.

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Table S1: Cities for analysis of trends between pre and post Kyoto periods

City	Country	Base inventory year	**Total inventory (tons of CO_2 equivalent)**	**Trend ΔI (tons of CO_2 equivalent)**	**Trend normalized to base (ε)**	Base inventory year	**Total inventory (tons of CO_2 equivalent)**	**Trend ΔI (tons of CO_2 equivalent)**	**Trend normalized to base (ε)**
North Vancouver	Canada	2005	220415	**1279.7**	**0.005806**	2008	223475	**-8021**	**-0.03589**
Thane	India	1990	2327233	**-53869.4**	**-0.02315**	2007	1411454	**356176.8**	**0.252347**
Rajkot	India	2007	1	**592212**	**0.671364**	2009	1	**486282**	**0.235314**
Vaxjo	Sweden	1993	326763	**-4212.91**	**-0.01289**	2009	246396	**-5383.29**	**-0.02185**
Malmo	Sweden	1990	1425000	**3894.737**	**0.002733**	2009	1499000	**49968.5**	**0.033335**
City of Vasteras	Sweden	1990	918500	**-5154.92**	**-0.00561**	2008	822100	**-19272.4**	**-0.02344**
Evanston	United States	2005	1003807	**17238.4**	**0.017173**	2008	1045590	**-34964.7**	**-0.03344**
Santa Monica	United States	1990	822511	**2750.486**	**0.003344**	2007	862661	**-16227**	**-0.01881**
Boston	United States	2005	7535298	**21815.9**	**0.002895**	2008	7441878	**-198363**	**-0.02665**
Boulder	United States	2006	1814978	**21528**	**0.011861**	2008	1858034	**-35107**	**-0.01889**
North Vancouver *	Canada	2005	2712	**-51**	**-0.01881**	2007	2610	**-51.9643**	**-0.01991**
Thane *	India	1990	42379	**-779.176**	**-0.01839**	2007	29133	**5307.2**	**0.182171**
Stockholm*	Sweden	2006	320000	**-24000**	**-0.075**	2007	296000	**-25500**	**-0.08615**
Växjö*	Sweden	2005	15225	**-275.167**	**-0.01807**	2011	13574	**-2094.5**	**-0.1543**
Evanston *	USA	2005	24559	**-887.5**	**-0.03614**	2007	22784	**-1183.5**	**-0.05194**
Santa Monica*	USA	1990	24108	**892.2397**	**0.03701**	2007	39245	**-358.5**	**-0.00913**

*Government inventories

[1]local governments have requested upon reporting to the Carbonn Climate Registry that their total GHG emissions remain confidential